A HARDENED, SELF-RECORDING INSTRUMENTATION DEVICE FOR EXPLOSIVES STORAGE SAFETY RESEARCH

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BACKGROUND

Over the last several decades, research on explosives storage safety has been a subject of steadily increasing interest, not only in the U.S., but in many countries around the world where significant amounts of military ammunition must be stored in areas surrounded by encroaching civil development. This research normally is performed (a) to refine the definitions of hazardous areas (Quantity-Distances, or Q-D's), or (b) to develop improved storage methods which will reduce the hazards produced by an accidental explosion.

Many explosive tests have been conducted to simulate accidental explosions, and to measure the blast and shock effects for specific test conditions. Until recently, the primary areas of interest for such measurements were at distances where the blast and shock levels are near the threshold for damage to surrounding structures. Additional measurements are made at closer distances mainly to establish attenuation rates of the blast and shock, as a function of distance.

Within the last few years, however, it has become increasingly important to record more intense levels of blast effects, very near the explosion source. Such data are needed to develop better understandings of the explosion process (for example, the propagation of a detonation from one unit of munitions to another), or to evaluate the performance of storage structure configurations, barriers, or other concepts designed to contain, reduce, or simply survive the intense blast effects from an accidental explosion.

The Explosion Effects Division of the Waterways Experiment Station (WES) has specialized for many years in the measurement of blast, shock, and other effects of explosions. In 1986, WES made airblast and ground shock measurements for a U.S. Air Force test simulating an accidental detonation of 28 MK-84 bombs in an earth-covered magazine, or "igloo." Hardened blast pressure gages were installed inside the igloo to help evaluate the performance of "buffer" walls in limiting the propagation of the explosion.

Although the gages were able to record peak pressures in excess of 103 MPa (15,000 psi), the pressure records ended only a few milliseconds after the peak reading, due to destruction of the gage cables by the explosion.

From this test and similar experiments, it was evident that a measurement technique was needed which would not only allow the sensor to survive intense explosion loads, but would also enable the recording system to survive long enough to capture complete records of the explosion effects. To achieve this capability, WES began development of a hardened, self-recording measurement package which would eliminate the need for cables connecting the sensor to a remote recording unit.

HDAS DESCRIPTION

The product of this development effort was the Hardened Data Acquisition System, or HDAS. The basic HDAS module is a miniature, solid-state device containing an instrumentation amplifier, an auxiliary gain amplifier, an 11-bit flash analog-to-digital converter, a 128 kiloword (16-bit word) memory, and an output interface (Reference 1). The module is encapsulated in an epoxy/glass microbead matrix to provide shock hardening. Together with a shock-hardened 10.5-volt battery power supply, the complete unit measures only 15 cm long, 6.5 cm wide and 4 cm thick (see Figure 1).

The data sample rate is adjustable from 1 MHz down to less than 10 kHz, with associated recording times of 120 msec to 12 seconds, respectively. The recorder can be activated either by a small, expendable cable connection, or by an internal shock-sensitive switch. Data is recorded in a continuous loop mode after the device is activated. The internal battery allows the data to be stored for five months or more. After the unit is recovered following a test, it can be connected to a portable computer and a plotter to immediately produce finished plots of the data record. Filtering, baseline correction, and single and double integration can also be performed within a very few minutes, as desired.

TEST RESULTS

Over the last few years, WES has used the HDAS system on a wide variety of explosives safety tests -- sometimes successfully; sometimes not. As with any complex, developmental device, unexpected problems occur that must be solved in a careful, deliberate process. This paper describes some of the successes, and some of the problems, that have been experienced with HDAS.

The first use of HDAS on an explosion test was in 1988 (Reference 2), in a project sponsored by the KLOTZ Club, which simulated an accidental detonation of 20,000 kg of explosives in a shallow underground magazine (Figure 2). Standard, hard-wired gages were used to measure the detonation pressures in the chamber, the short access tunnel, and the outside area. Two HDAS gages were installed in the floor of the tunnel entrance. As expected, the standard gages inside the chamber and tunnel recorded only the first few milliseconds of pressure, before destruction of the gage cables. The detonation produced a large crater, extending beyond the tunnel entrance. After some hours of digging, the HDAS units were located in the crater rubble. The top of the gage located 1 m outside the tunnel entrance had originally been installed with its top surface projecting about 1 cm above the concrete floor of the tunnel entrance (due to a construction error). As a result, the intense "plasma" of detonation gases going out of the tunnel (before the chamber cover was blown away) eroded the metal cover of the unit, burning up the pressure gage after about 20 msec. The second HDAS unit was properly installed flush with the surface, and was undamaged. As can be seen in Figure 3, it produced a complete record of the pressure history.

In 1990, the United Kingdom and Australia jointly conducted a test at Woomera, Australia, involving the detonation of 75,000 kg of explosives to evaluate the survivability of a new design for an earth-covered magazine, called a "Spantech" structure (Reference 3). HDAS units were used to record the internal pressures in the donor magazine (Figure 4), as well as the pressure loads on adjacent Spantech structures, and in the free-field around the test. Good records were obtained from all of the HDAS units outside the donor magazine, and from units on the side walls in the interior of the donor structure. As shown in Figure 5, the measured interior pressure reached 72 MPa (10,500 psi).

The interior gages near the top of the donor structure were thrown several thousand metres by the explosion. Several were never found; those that were found survived the detonation itself, but were destroyed by their impact with the ground due to an inadequate design of the protective canisters containing the HDAS units.

In later Spantech tests, HDAS units with redesigned canisters were placed on top of the donor magazine to measure the initial, or "break-away", motions of the structure. The canisters were again thrown several thousand metres, but those that were located survived the impact and produced good motion data (Figure 6).

Also in 1990, WES conducted a series of experiments for the U.S. Army Program Manager for Ammunition and Logistics (PM/AMMOLOG) to evaluate the effectiveness of parking ammunition trucks in shallow, covered trenches, as an expedient method for reducing the blast and debris hazards from an accidental explosion of an ammo truck at a temporary field storage site (Reference 4). One of these tests involved the detonation of an unprotected ammo truck (parked in the open) containing 1,500 kg (net explosive weight) of 155-mm projectiles and propellant canisters, to provide control data on the blast pressure and debris hazard from such an accident.

To measure the initial velocities of debris thrown out by the explosion, HDAS units containing accelerometers were installed inside empty 155-mm projectiles, and placed around the live ammunition (Figure 7). The instrumented projectiles were separated from the live rounds by a single layer of sandbags, to prevent their destruction by the detonation. Unfortunately, a single layer of sandbags was not enough. While the instrumented projectiles were not destroyed, they were deformed enough to crush the HDAS units inside.

On the third experiment in this series, two ammo trucks were parked rear end-to-rear end in a single covered trench, with a 1.5-m thick sand wall between them. The purpose was to prove that an accidental explosion of one ammo truck would not propagate to the other, even when the trucks were confined by the trench walls and cover. HDAS units were again installed in empty projectiles, and placed on the top and rear of the acceptor truck to measure the blast pressure environment from the detonation of the donor truck (Figure 8). These units survived the detonation, and produced complete pressure histories (Figure 9).

One of the most recent attempts to use the HDAS system was in support of the U.S. Navy's program to develop an advanced design of an earth-covered magazine, called the High Performance Magazine, or HPM. The HPM concept is based on limiting the total amount of explosives involved in an accident, by using barrier walls between individual storage bays within a magazine. The barrier walls must be thick enough to prevent a detonation in one bay from propagating to adjacent bays, yet small enough to allow an efficient volume of munitions to be stored in the magazine.

In a recent series of experiments by the U.S. Naval Civil Engineering Laboratory, different barrier designs were tested to evaluate their effectiveness in preventing the propagation of a detonation from one stack of bombs to another. In small-scale tests using 155-mm projectiles to model the acceptor bombs, HDAS units were used to measure the acceleration of the acceptor rounds impacted by the barrier material. The donor in this test was an MK-82 bomb. Figure 10 shows such a measurement for an acceptor round located 15 cm behind a 1-m thick sand wall, which was 1.0-m from the donor bomb. The HDAS unit record a peak acceleration of about 750 g's, and a peak velocity of about 10.5 m/sec induced in the acceptor projectile by the impact of the well. Unfortunately, a number of the HDAS units in this test failed to operate properly, possibly due to an electromagnetic pulse induced in the HDAS trigger circuit by the detonation. The pulse apparently caused the HDAS memory to stop recycling before the arrival of the shock wave.

CONCLUSIONS

The HDAS system shows great promise as a revolutionary technique for investigating intense explosion environments that current instrumentation systems cannot survive. The HDAS concept is still in the developmental stage, however. Although HDAS units have been used to make measurements of explosion effects that would have been impossible with normal instrumentation methods, several problems have been encountered with HDAS use in very severe explosion environments.

The most important problems to date are the HDAS units' vulnerability to crushing forces, being lost (i.e., not found after a test), and the recent case of electromagnetic interference. The crushing problem has largely been solved by redesign of the protective containers. An effort is also underway at WES to develop a miniature radio transmitter that can be included in HDAS packages used on large explosive tests. The transmitter should allow the HDAS units to be found up to several kilometers away after the test. A prototype transmitter has been designed, and preliminary experiments have confirmed its ability to survive high levels of detonation shock.

When the current work to overcome the operational problems described here is complete, the HDAS system will be turned over to the private sector for commercial production. At that time, it will become widely available as, we hope, a significant new tool for explosives safety research.

ACKNOWLEDGEMENT

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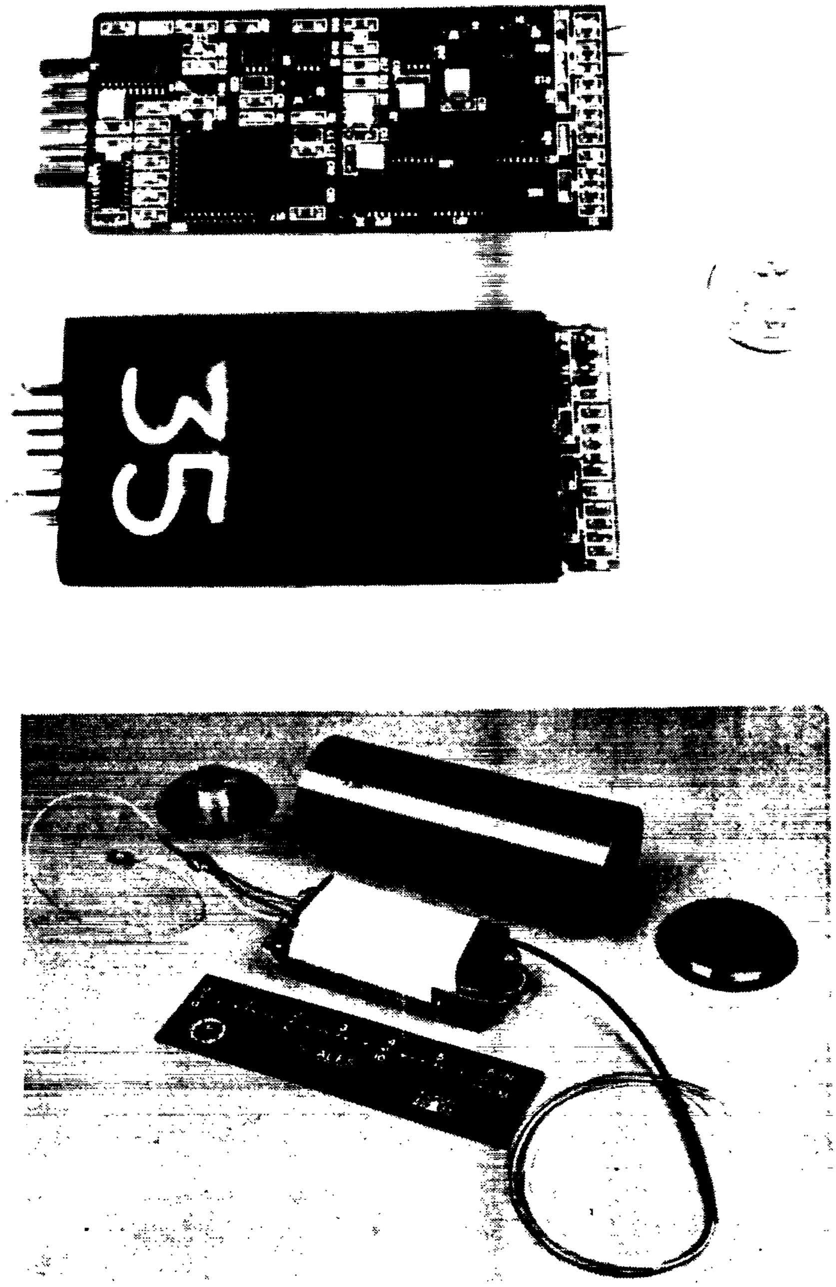


Figure 1. HDAS circuit board before and after encapsulation in epoxy case (top), and mated with batteries prior to insertation with sensors in protective canisters (bottom).

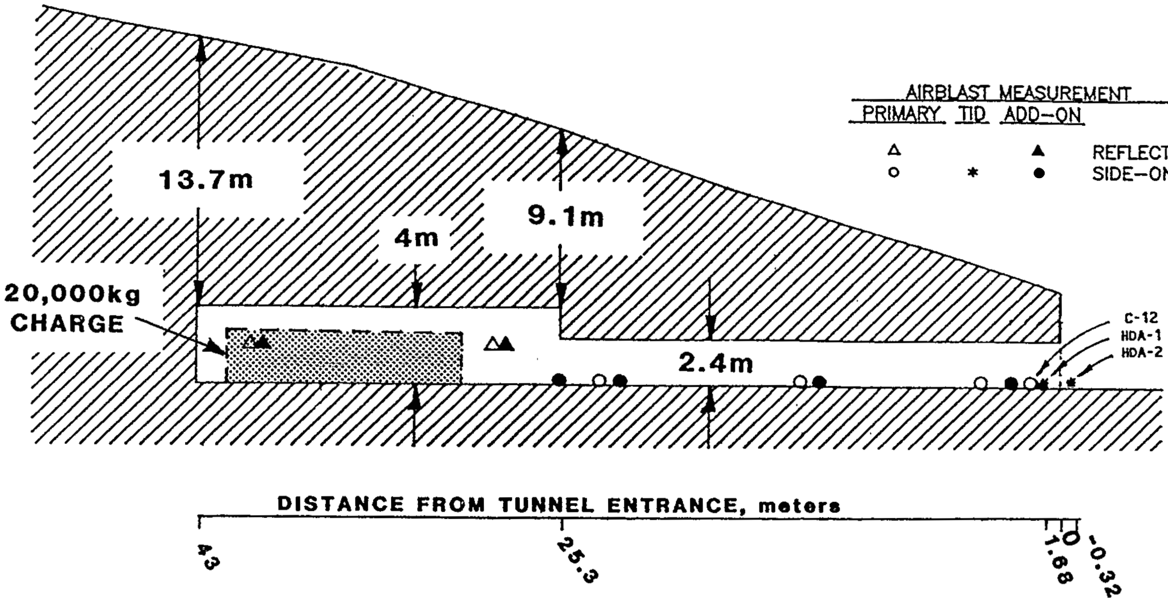


Figure 2. Elevation view of 1988 Klotz Club magazine test, showing locations of standard pressure gages (circles and triangles) and HDAS units (HDA-1 and -2).

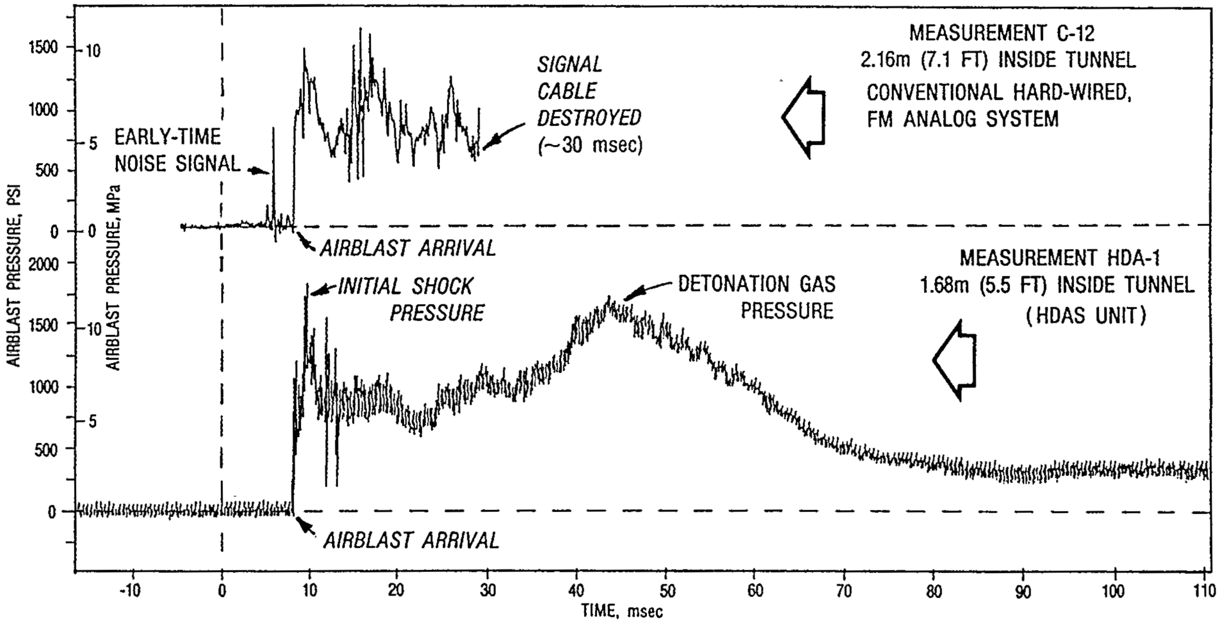


Figure 3. Comparison of pressure histories recorded by pressure gage (top) and HDAS unit, for 1988 Klotz magazine test.

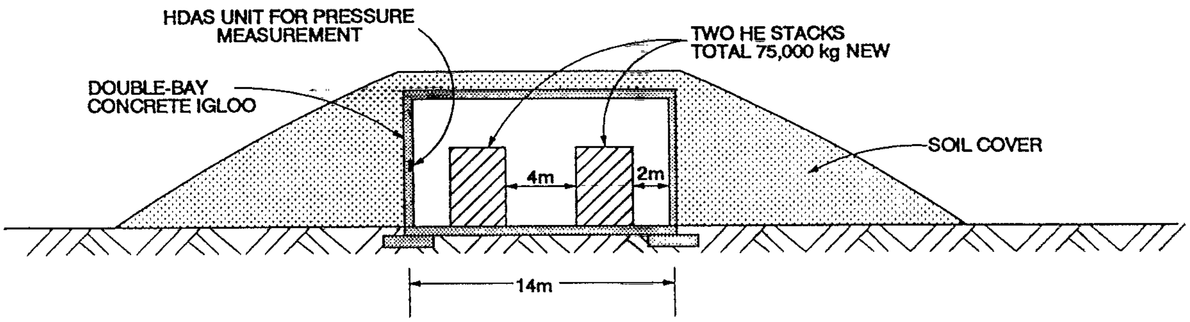


Figure 4. HDAS unit location to measure internal blast pressure from destructive test of a donor igloo magazine at Woomera, Australia.

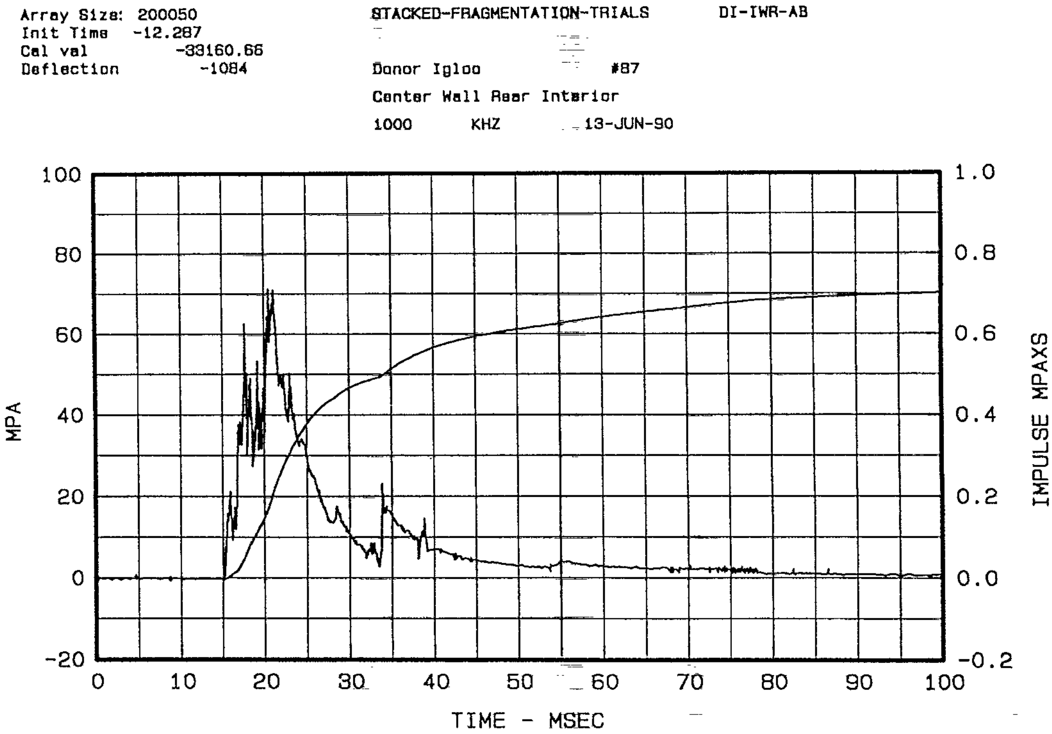


Figure 5. Blast pressure and impulse histories recorded by HDAS unit shown in Figure 4.

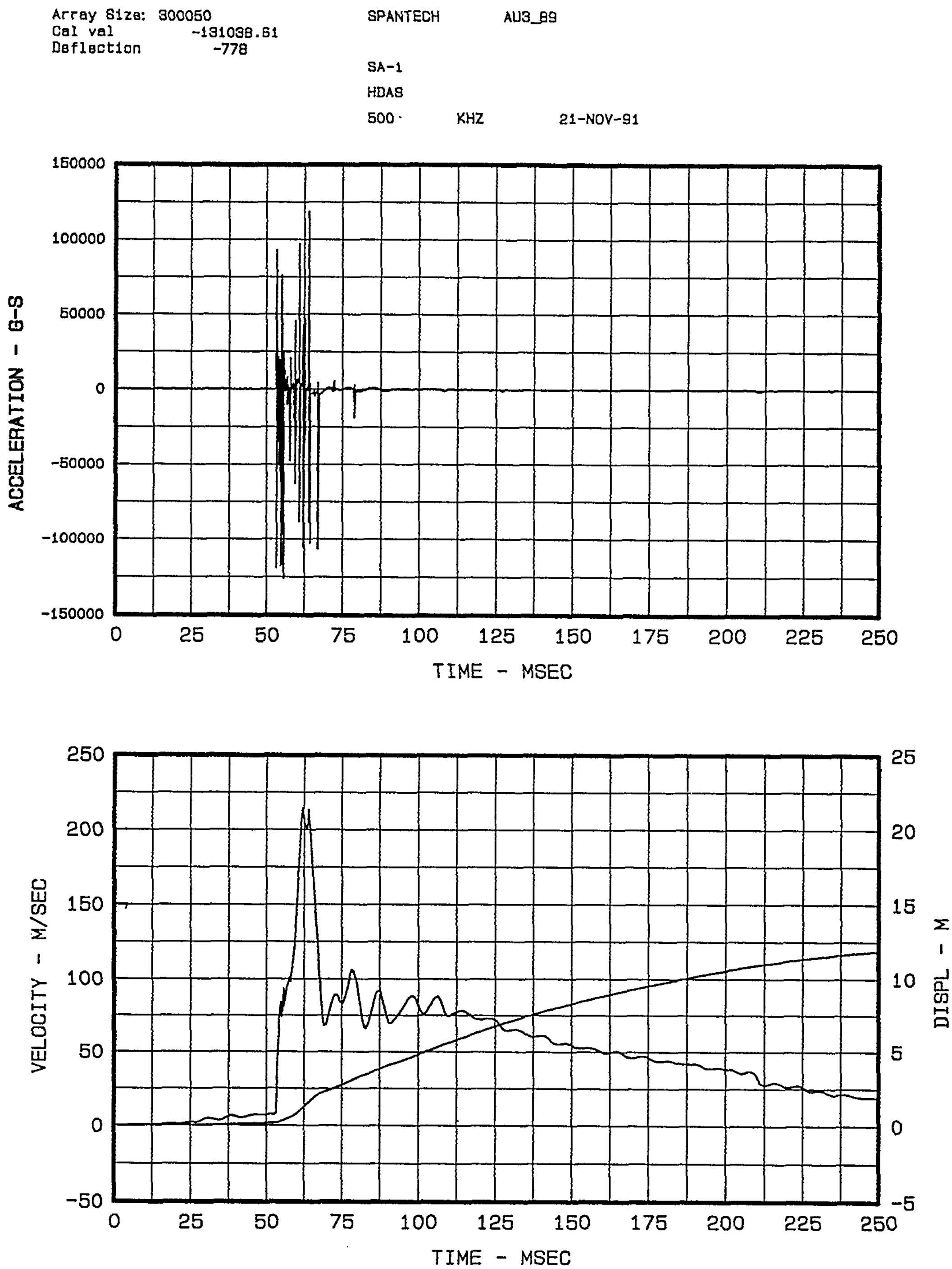
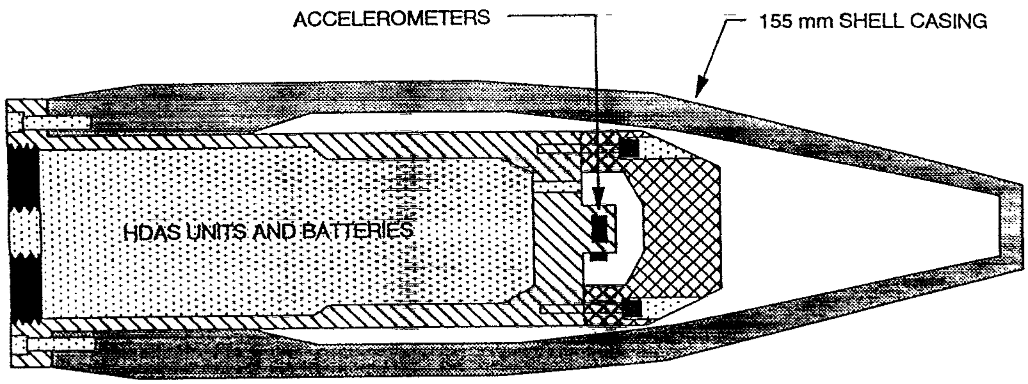


Figure 6. Records obtained by HDAS accelerometer units installed in top of Spantech concrete igloo to measure initial debris velocities for structure breakup by detonation of 75,000 kg of explosives. Acceleration record (top) was integrated to produce velocity and displacement histories.



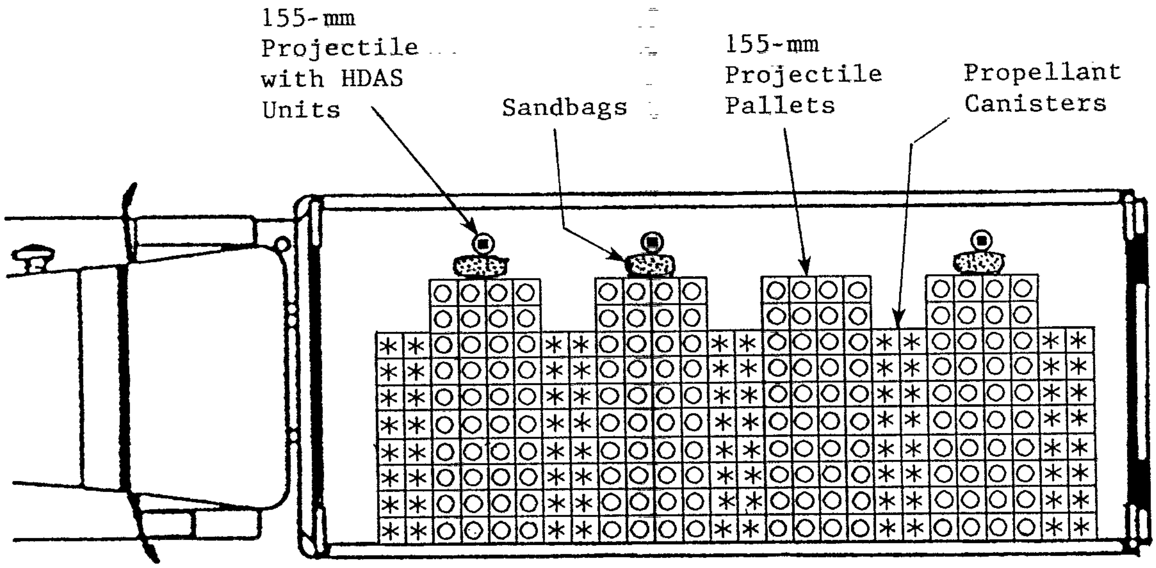


Figure 7. Installation of HDAS units with accelerometers in empty 155-mm projectiles (top) and placement of HDAS-instrumented projectiles on truckbed with Unit Basic Load of 155-mm ammunition.

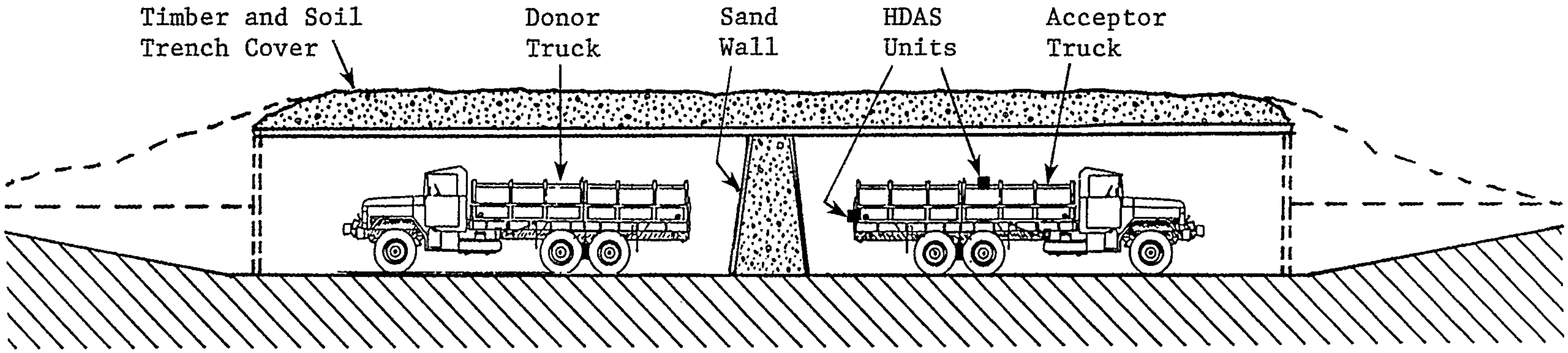


Figure 8. Locations of HDAS units used to measure blast presures in Acceptor truck bay from detonation of Donor truck (Two-Truck Trench Test).

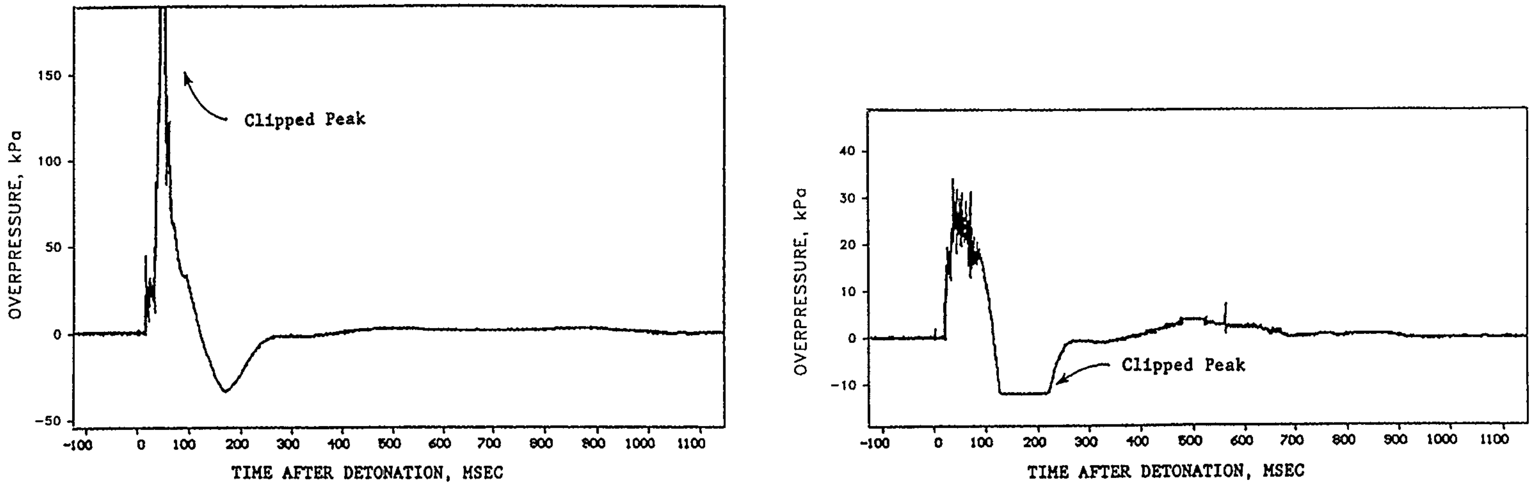


Figure 9. Blast pressure histories recorded by HDAS units for Two-Truck Trench Test; at rear of Acceptor truck (left) and on top of acceptor ammo load (right).

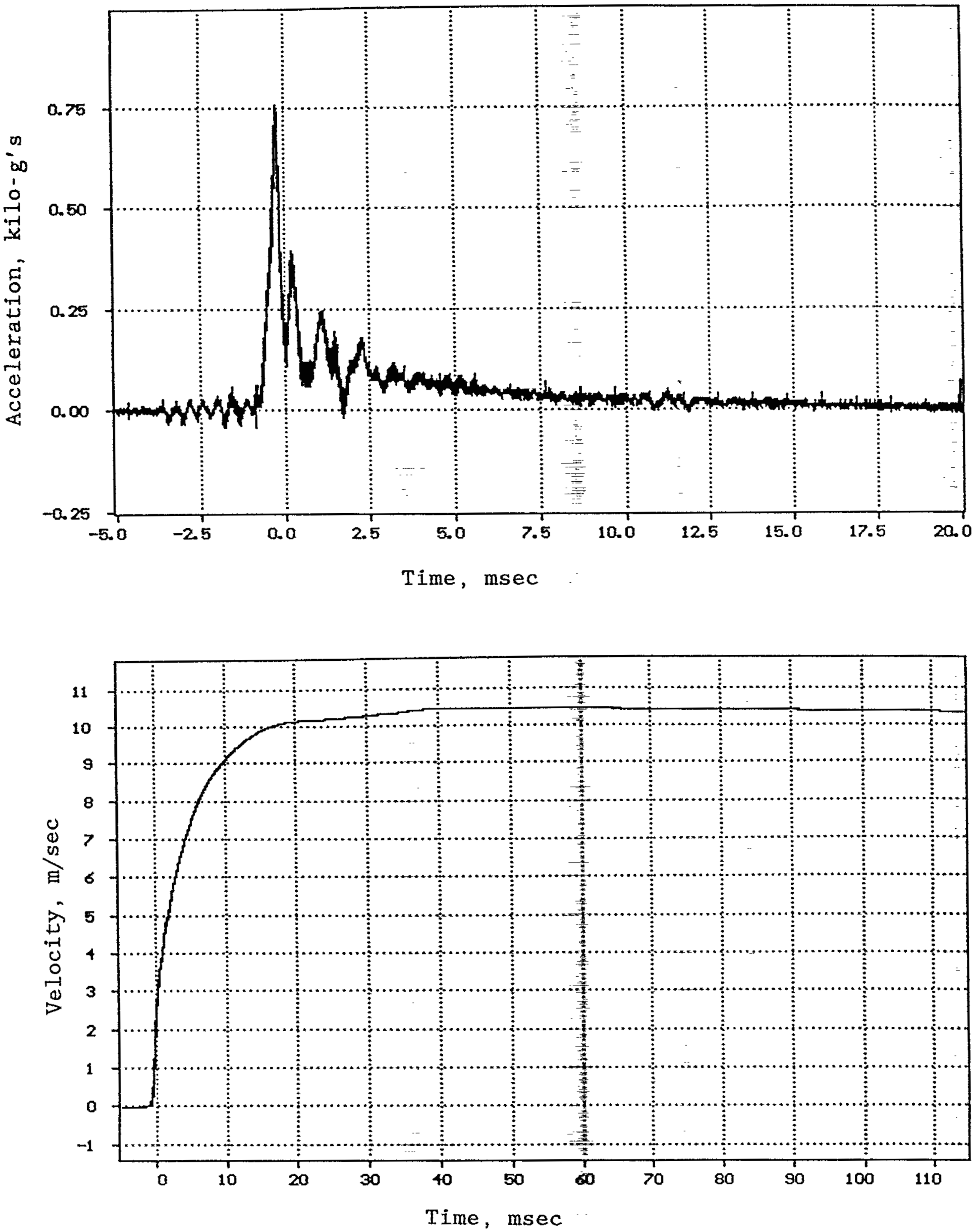


Figure 10. HDAS-recorded acceleration (top) and velocity of acceptor (inert 155-mm) projectiles induced by impact of sand wall between projectiles and donor detonation of a MK-82 GP bomb.